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FINAL REPORT

TO THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

on NASA Grant NAG 5-1921

"Lithospheric Dynamics Near Plate Boundaries"

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PROJECT SUMMARY

Introduction

In 1991 we proposed a four-year project to the NASA DOSE (Dynamics of the Solid Earth) Program to analyze changes in vector baselines measured by space geodetic techniques in terms of quantitative models for the dynamics of lithospheric deformation near plate boundaries. The project was approved for four years of funding, beginning on 15 March 1992, under grant NAG 5-1921 to the Massachusetts Institute of Technology (MIT), where the Principal Investigator was a Professor of Geophysics.

On 1 September 1992 the PI assumed a new position as Director of the Department of Terrestrial Magnetism (DTM) at the Carnegie Institution of Washington. On 25 January 1993 we submitted a continuation proposal to support the second through fourth years of this project through DTM. The continuation proposal was approved, and funding for the second year of effort began on 15 March 1993 under NASA grant NAG 5-2206.

Thus the grant to MIT was only one year in duration, even though the research tasks which that grant supported will be carried out over four years, and for three of those years much of the research will be conducted at another institution. This report constitutes the final technical report for grant NAG 5-1921 to MIT, as well as a report of first-year progress for the research project as a whole.

Research Objectives

One of the successes of the Crustal Dynamics Program (CDP), the precursor of DOSE, was the measurement of the relative velocities of many of the Earth's major tectonic plates. An important result was that the stable interiors of the plates are in relative motions at rates comparable on time scales ranging from years to millions of years, implying that the effects of episodic slip along plate boundaries are not felt as time-dependent motion in plate interiors. The challenge to the next decade of space geodetic measurements of horizontal crustal motions is to document the nature of deformation and its temporal behavior along plate boundaries and to understand the dynamics of that deformation. To address this challenge, the research we proposed for the four-year period 1992-1996 consists of three broad and interconnected tasks:

(i) Determination of the time-dependent deformation along the Pacific-North American plate boundary from the Gulf of California to the Big Bend region of the San Andreas fault.

(ii) Development of dynamic models for deformation and earthquake cycles along major strike-slip fault systems, with application to the Pacific-North American plate boundary.

(iii) Development of dynamic models for gravity-driven extension of areas of high topography, with application to the Altiplano in South America.

In this technical report, we include only summaries of these tasks, as well as of the progress toward their accomplishment during the first project grant year at MIT.

Deformation along the Pacific-North American Plate Boundary: Gulf of California to the Big Bend. This task is aimed at clarifying the deformational characteristics of the North American-Pacific plate boundary along its transition from an oceanic spreading center in the Gulf of California to continental strike-slip faulting along the San Andreas fault system in California. A primary source of information continues to be Global Positioning System (GPS) measurements from three separate, but closely coordinated projects, the Jet Propulsion Laboratory (JPL)/Oregon

State University (OSU) project to measure deformation across the Gulf of California, the University of Texas at Dallas (UTD) project with Mexican collaborators in the Mexicali Valley and northern Baja California region, and the MIT-led project in the Salton Trough-southern San Andreas region. We are working to combine these GPS measurements through a simultaneous reduction using the MIT GPS analysis software (GAMIT) to obtain a map of the present-day velocity field and to search for evidence of time-dependent velocities. This velocity field will be interpreted in light of other geophysical and geological information to enhance our understanding of plate tectonic processes operating in this complex and important transitional region.

Dynamics of Strike-Slip Plate Boundaries. Elucidating the nature of deformation and its temporal behavior along major plate boundaries and understanding the dynamics of that deformation constitute high priority goals for the next decade of space geodesy. Under this task we address this problem through the development of dynamic models for deformation along major strike-slip fault systems and the testing of these models against geodetic and other data for the Pacific-North American plate boundary from the Gulf of California to the Big Bend section of the San Andreas fault. Particular attention is being paid to the question of whether fault zones are demonstrably weaker than surrounding lithosphere and to the transition from oceanic to continental transform behavior along this plate boundary. We envision the development of models that can accommodate the geometrical complexity of the region, that can be utilized to address specific questions of high interest (e.g., width of plate boundary, depth of seismic faulting, nature and magnitude of aseismic slip, evidence for or against stress diffusion and earthquake triggering), and that can be modified and updated as geodetic data span longer time intervals and achieve greater measurement and spatial resolution.

Dynamics of Gravitational Spreading of High Terrain. The gravitational potential energy of high topography is believed to contribute to the extension of regions such as Tibet, the Altiplano and the Turko-Iranian plateau. As compressive forces build up mountain ranges, the crust thickens and becomes progressively weaker as it moves toward thermal equilibrium, making it susceptible to deformation by even relatively low stresses. Stresses due to the high topography may cause extension in the plateau, thrusting in the surrounding lowlands, and strike-slip faulting in transitional regions. Under this task we are developing finite-element models of gravitational spreading to estimate surface strain rates and the distribution of deformational features. In addition to thermal considerations, we intend to concentrate on the effects of variations in elevation, compensation, and regional compressive stress. We will test the models against GPS data planned to be acquired in Andean South America jointly by JPL, Northwestern University, the University of Miami, and DTM, data recently obtained by the research group at the Freie and Technische Universitat Berlin along an E-W transect across the Puna plateau in the Andes at 23°-25°S, as well as seismic and geological data for the Andean region.

Research Progress

The focus of the research under this project during the first grant year was on several problems broadly related to the nature and dynamics of time-dependent deformation and stress along major seismic zones (the first two tasks above), with an emphasis on western North America but with additional work on seismic zones in oceanic lithosphere as well. The principal findings of our research to date are described in the publications and abstracts of oral presentations listed below. The full texts of these papers and abstracts have been provided to NASA in a semiannaul status report and in the progress report included in the most recent continuation proposal for this project.

PUBLICATIONS SUPPORTED BY NASA GRANT NAG 5-1921

Larsen, S., R. Reilinger, H. Neugebauer, and W. Strange, Global Positioning System measurements of deformations associated with the 1987 Superstition Hills earthquake: Evidence for conjugate faulting, *J. Geophys. Res.*, *97*, 4885-4902, 1992.

Larsen, S., and R. Reilinger, Global Positioning System measurements of strain accumulation across the Imperial Valley, California: 1986-1989, *J. Geophys. Res.*, *97*, 8865-8876, 1992.

Bergman, E. A., and S. C. Solomon, On the strength of oceanic fracture zones and their influence on the intraplate stress field, *J. Geophys. Res.*, *87*, 15,365-15,377, 1992.

Reilinger, R., and S. Larsen, Present-day deformation in the Salton Trough, southern California, in *Scientific Results of the Crustal Dynamics Project*, Geophys. Mon. Ser., Amer. Geophys. Un., Washington, D.C., in press, 1993.

Wolfe, C. J., E. A. Bergman, and S. C. Solomon, Oceanic transform earthquakes with unusual mechanisms or locations: Relation to fault geometry and state of stress in the adjacent lithosphere, *J. Geophys. Res.*, *98*, in press, 1993.

Sauber, J., W. Thatcher, S. C. Solomon, and M Lisowski, Crustal strain and the 1992 Mojave Desert earthquakes, *Nature*, submitted, 1993.

ABSTRACTS OF ORAL PRESENTATIONS SUPPORTED BY NASA GRANT NAG 5-1921

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Smith, L., R. E. Reilinger, and B. H. Hager, Modeling post-seismic viscoelastic deformation for the 1959 Hebgen Lake earthquake, in *1993 Spring Meeting, Eos Trans. Amer. Geophys. Un., 74*, Suppl., 106, 1993.

Lee, S.-M., J. Lin, and S. C. Solomon, A mechanism for near-ridge normal faulting at fast-spreading mid-ocean ridges, in *1993 Spring Meeting, Eos Trans. Amer. Geophys. Un., 74*, Suppl., 297, 1993.